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Report of Green Thread Pipe Installation at Lualualei, HI and Jim Creek, WA VLF Sites: Changes from 1997 to 2001

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13. ABSTRACT (*Maximum 200 words*)

This report summarizes the on-going study of Green Thread fiberglass piping that was installed at the Laulaulei, HI and Jim Creek, WA VLF sites. This Green Thread pipe was introduced to these VLF sites in 1996 and 1997, respectively, as a replacement for the original materials used to conduct cooling water to and from the power amplifier tubes. The Naval Research Laboratory was tasked with monitoring the changes in water quality with the aging of the Green Thread pipe. Yearly monitoring of standard chemical and physical variables significant for the sites such as: dissolved copper; pH, resistivity, dissolved organics, dissolved oxygen, sacrificial target use, Barnstead cartridge usage, PA tube failure rates, etc., is conducted. To date, the pipe has not introduced any apparent system degrading components.

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VLF	Dissolved copper	Oxygen electrodes
Power amplifier tubes	Chemical corrosion	Dissolved oxygen

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REPORT OF GREEN THREAD PIPE INSTALLATION AT LUALUALEI, HI AND JIM CREEK, WA VLF SITES: CHANGES FROM 1997 TO 2001

BACKGROUND

Both Lualualei and Jim Creek used ceramic coil insulators to carry the cooling water to/from the power amplifiers (PA) and the intermediate power amplifiers (IPA)(Lualualei only). Because of the impending shortage of these ceramic insulating coils (manufacturer was no longer going to be making the ceramic coils and a replacement source was not available), a change to filament wound/epoxy resin piping was initiated. The fiberglass pipe chosen was produced by Smith Fiberglass Products, Inc. The Green Thread designation pipe was chosen because its physical and chemical properties were appropriate for the intended purpose.

A trial installation was performed on a single IPA at the Lualualei site in early 1996 by Pacific-Sierra Research Corporation. After a successful trail period, the Lualualei site was converted to the fiberglass pipe in October 1996 by Continental Systems. In February 1997, the ceramic insulating coils were replaced at the Jim Creek site with the selected fiberglass pipe by Continental Systems. All of the fiberglass piping was cut and assembled on site to fit the prevailing installation constraints for each of the sites. One of the changes that occurred with the installation of the new piping was that the total path length of the fiberglass piping was shorter when compared to the replaced ceramic coil.

In November 1997, it was noticed that the there was a darkening or a dark coating/deposit on the interior of the fiberglass tubing at the Lualualei site. The fiberglass pipe has a somewhat translucent light yellow/green color when new. The fiberglass pipe at the Jim Creek site was also undergoing a color change. The color change was not as dramatic at the Jim Creek site as it was at the Lualualei site (it also had less service life than Lualualei).

An investigation was initiated to determine the cause(s) of the color change in the pipe and also if the cooling system was undergoing some change(s) that could potentially become a future problem. Several possible causes for the darkening of the fiberglass pipe were: 1) dissolved oxygen in cooling water was greater than 0.5 ppm and reacting with the fiberglass; 2) cupric oxide buildup was occurring due to the increase of dissolved oxygen in the cooling water; 3) fiberglass pipe was undergoing a chemical change due to the temperature of the cooling water; 4) a bacterial/fungal growth on the inside of fiberglass pipe; 5) reaction of plasticizers diffusing from the fiberglass pipe with the heated cooling water. A discussion was held with a Ms. Shawna Pierce, technical representative at Smith Fiberglass Products Inc., in which the operating conditions at

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both VLF sites were described. The opinion of Ms. Pierce based on experiences to date with the Green Thread fiberglass pipe is that the darkening of the pipe is a common and expected result in conditions similar to both VLF sites. The pipe will darken with age and the degree of darkening will also increase with elevated operating temperatures. Ms. Pierce commented that she has seen some Green Thread fiberglass pipe become almost black when operating temperatures reach 200° F. Ms. Pierce stated that the darkening did not weaken or change the physical or chemical properties of the fiberglass pipe. When asked what the expected lifetime of the fiberglass pipe would be in the given circumstances, Ms. Pierce declined to comment "officially" but stated that it was her opinion that it would last for at least 20 years.

Smith Fiberglass Products Inc. publishes Bulletin No. ES600, dated 1 July 1994, to be used as a reference guide for selecting/evaluating the proper type of fiberglass pipe for use in various installations. The bulletin includes information about three different types of fiberglass pipe: Red Thread II; Green Thread; and Poly Thread. This publication indicates that the Green Thread fiberglass pipe can be employed in environments using distilled or deionized water with an upper operating water temperature of 205°F. The operating conditions at Lualualei are distilled water with an upper operating temperature of 140°F. Jim Creek also uses on-site produced distilled water with an upper operating temperature 110°F. The VLF operating conditions at both sites certainly fall within the acceptable range for use of the Green Thread pipe.

It was decided that site visits would be conducted to each site to verify the information that was obtained from the Smith Fiberglass technical representative and establish a pictorial and scientific base line for future evaluation of the fiberglass pipe at both sites.

Several parameters were identified for investigation upon arriving at the sites. These parameters were: 1) measurement of the dissolved oxygen in the cooling water; 2) conductivity readings of the cooling water; 3) replacement frequency of the Barnstead purification cartridges; 4) dissolved copper concentration in the cooling water; 5) erosion rate of copper targets; 6) seasonal operating temperature of the cooling water; 7) color photographs of all the sections of fiberglass pipe.

LUALUALEI SITE

At this site there are two PA tanks (PA1, PA2) and two IPA tanks (IPA1 and IPA2). There is a Barnstead purification loop for each of the PA tanks and one for the IPAs (only one IPA in Barnstead loop at a time). At the time of the start of this long term evaluation, dissolved oxygen concentrations were obtained using Chemet tubes. Since that time, dissolved oxygen monitoring systems have been installed on the two PA loops and a single system on the combined IPA loops. Consequently dissolved oxygen concentrations are constantly visually available. Table 1 lists the values for several of the parameters indicated above at the time of the visit in late January 1998.

	PA1	PA2	IPA1	IPA2
Oxygen ppm - Barnstead/Chemets	1.5	0.4	0.4	----
Oxygen ppm - At tank/Chemets	1.5	0.2	0.2	0.3
Resistivity - meg-Ω	18.5	17.8	---	---
Dissolved copper - ppm	0.15	NDL	0.300	0.08
Nitrogen flow rate – SCF	4	4	2	2
Particles in water	yes	no	no	no

NDL = Near detection limit (0.04)

Table 1. Dissolved oxygen, resistivity, and dissolved copper in water from Lualualei, HA.

The dissolved oxygen concentrations in the cooling water (< 0.5 ppm) were within the limits necessary to prevent chemical corrosion in PA2 and the IPAs. PA1 had a dissolved oxygen concentration in the cooling water of 1.5 ppm. In discussions with site personnel, water leaks had been identified for PA1 and were to be repaired. These leaks caused the dissolved oxygen to be higher than the recommended 0.5 ppm level due to incursion of oxygen from the air into the cooling system. Follow up reports showed the leaks were repaired and the oxygen level returned to acceptable levels.

Table 2 shows the values that were obtained for the various parameters collected in March 2001. All the values are within acceptable limits and do not differ significantly from the information obtained in May 1998 (1) and May 2000 (2). Oxygen measurements

	PA1	PA2	IPA1	IPA2
Oxygen ppm - Oxygen electrode	0.01	0.01	0.05	-----
Oxygen ppm - Barnstead/Chemets	0.05	0.10	0.05	-----
Oxygen ppm - At tank (Chemets)	0.2*	0.2*	0.2*	0.3*
Resistivity - meg-Ω	18	18	13	----
Dissolved copper - ppm at tank	0.13	0.14	0.2	0.3
Dissolved copper - ppm/Barnstead	0.04	0.09	0.04	-----
pH at tank	7.1	7.3	6.9	6.7
Temperature - °F	74#	74#	75#	74#
Nitrogen flow rate – SCF	4	4	2	2

* extremely difficult to get sample via tank spigot without bubbles.
# Power to PAs shut off due to short in East Tower

Table 2. Dissolved oxygen, resistivity, dissolved copper, pH, temperature and nitrogen flow recorded for Lualualei in March 2001.

were made at the cooling tanks and at the Barnstead filters using Chemets. These values were compared with the values from the oxygen electrode and their respective

transmitting units. Very good agreement was obtained for PA1 and the IPA(s). The Chemets oxygen value was an order of magnitude higher than the oxygen electrode for PA2. This oxygen electrode will need to be recalibrated on the next site visit. At the present time, the oxygen concentrations for the system as a whole are well below the upper limit of 0.5 ppm for CuO formation. The higher oxygen values collected at the tanks are a function of the collection procedure and do not reflect adversely on the nitrogen sparging system. The dissolved copper concentrations are extremely low. The nitrogen sparging system is successful in preventing chemical corrosion (dissolved copper) and the subsequent deposition of copper oxide on the PA and IPA tubes.

The resistivities for the water cooling systems were very good. Checking the logs for the PA Barnstead cartridge replacement times indicated that the cartridges were providing good service time throughout this study period. There has been no increase in the change out frequency of the cartridges since the fiberglass piping was installed. The IPA Barnstead system was installed in June of 1997 and its change out frequency is comparable to the PA systems. Overall, the cooling system is working extremely well.

In 1998, several of the copper targets were examined with Mr. Neha and other site personnel. They all stated that they had not/were not noticing an increase in the erosion rate of the targets. In an attempt to gain some information about erosion rates, new targets were obtained from the storage room, however the new targets were of a much smaller gauge and of a different style than the old targets. Mr. Neha stated that they didn't have any other new targets to compare with the inplace targets since they hadn't changed them out in a very long time and hadn't ordered any or made any (it was not made clear which was the situation). In reviewing selected targets with Mr. Ross Fuller, station manager, the same results were obtained. Target replacement was rarely needed. At this time it was noticed that some of the targets were starting to show some dimunition, however it was not possible to attribute this to chemical or physical corrosion.

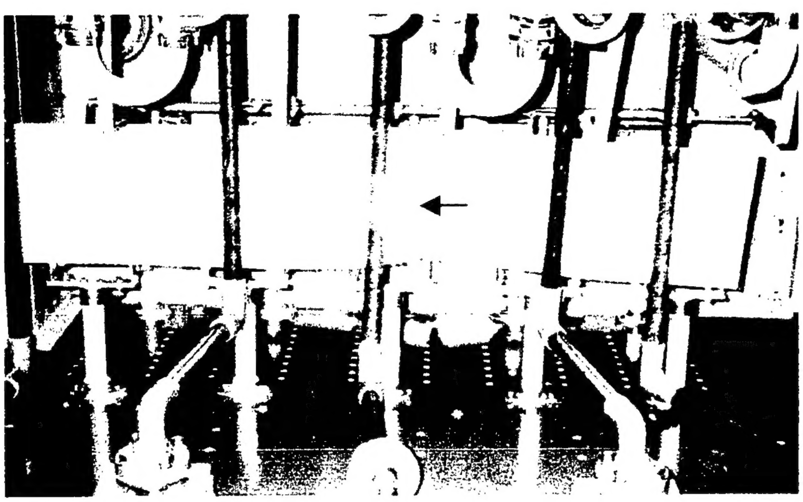

Figure 1. 1998 Photograph of the fiberglass pipe for PA 2 showing the color variations change in 1998 for PA2.

The coloration of the fiberglass pipe was photographed for use in future assessments of the aging process of the fiberglass pipe under VLF operating conditions. The discoloration of the pipe was mapped for all the cabinets. Figure 1 shows the color variations obtained for PA 2 in 1998. In general, the outlet pipes have a darker amber color than the inlet side pipes, but there were significant variations in the color for both inlet and outlet due to the variations in batch production of the pipe. There appeared to be color discontinuities in some of the piping where a splice has been used to join two pieces of pipe (indicated by arrow).

Figure 2 shows the same section of pipe (PA 2 left) photographed in March 2001. It is obvious that the Green Thread pipe has aged to a relatively uniform amber to dark amber color. There is no yellow green pipe coloration in the PA cabinets. Appendix A shows color changes of the Green Thread pipe for several PA cabinets for 1998, 2000, and 2001.

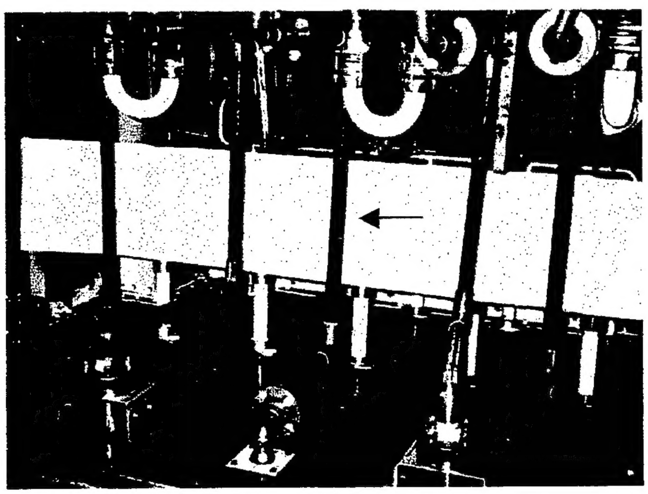

Figure 2. 2001 Photograph of the fiberglass pipe for PA 2 showing the color variations.

The arrow in figure 2 denotes the location of the splice indicated in figure1. The overall color of the latest photographs are darker than the earlier photographs, yet they portray a relatively true color change for the Green Thread pipe. Appendix A contains photographs showing selected color change from 1998, 2000 and 2001 for Lualualei and Jim Creek.

JIM CREEK SITE

This site has only two PA tanks, PA1 and PA2 and no IPA tanks. Each tank has a Barnstead purification loop consistent with the other water cooled VLF sites. This site has a Mettler-Toledo dissolved oxygen system which is inline before the Barnstead purification loop for PA2. Table 3 shows the values obtained in 1998. The dissolved oxygen concentration in the cooling water for PA2 which was in the operational mode during the site visit was 0.23 ppm. The resistivities of the water for PA1 and PA2 were

18 meg-Ω and 17.5 meg-Ω respectively. At that time, the Jim Creek site personnel had not noted an increase in the change out frequency of the generic dissolved ion cartridges nor has there been a decrease in the resistivity of the cooling water since the fiberglass piping has been installed.

	PA1	PA2
Oxygen - ppm	0.3	0.2
Resistivity - meg-Ω	17.5	18.0
Dissolved copper - ppm	1.21	1.12
Nitrogen flow rate – SCF	5	5
Temperature - °F	-----	104
pH - At Barnstead	6.6	6.6

Table 3. Values obtained in 1998 site visit to Jim Creek, WA.

At that time, selected copper targets were removed from six of the piping segments to allow for the collection of water and also for the collection of swipe samples in the vicinity of the fiberglass pipe. This procedure was performed on pipe segments that were dark amber and those that were light green/amber in color so as to gain some variation, if it exists, in dissolved copper concentrations in the cooling water that is in intimate contact with the fiberglass pipe (keeping in mind that the water is mixed back in the PA tanks). Copper concentrations obtained from the swab samples ranged from 0.03 to 0.06 mg/l. Site personnel stated that there was no increase in the erosion rate of the copper targets since the fiberglass pipe had been installed. As was the case with the Lualualei site, replacement targets were of a slightly different design so a comparison could not be made between the "in use" target and its replacement.

Table 4 lists the values obtained from the March 2001 site visit. As can be seen, the values are very similar to those collected in 1998 (1) and again to those collected in 2000 (2).

	PA1	PA2
Oxygen - ppm /Electrode	0.21	-----
Oxygen - ppm/Chemets/tank	< 1	< 1
Oxygen - ppm/Chemets/Barnstead	< 1	< 1
Resistivity - meg-Ω	18	17.5
Dissolved copper - ppm/Barnstead (before)	0.21	0.29
Dissolved copper - ppm/Tank	0.17	0.11
Nitrogen flow rate – SCF	2	> 1
Temperature - °F	94	-----
pH - At tank	7.05	6.47

Table 4. Dissolved oxygen, resistivity, dissolved copper, pH, temperature and nitrogen flow recorded for Jim Creek in May 2001.

The fiberglass pipe (figure 3) was installed in February 1997 and had been in service for approximately 13 months (May 1998). The upper summer time operating temperature for the cooling water is approximately 110°F. The color variations in the fiberglass pipe at that time were less intense at Jim Creek than those at Lualualei, HI. Once again, the

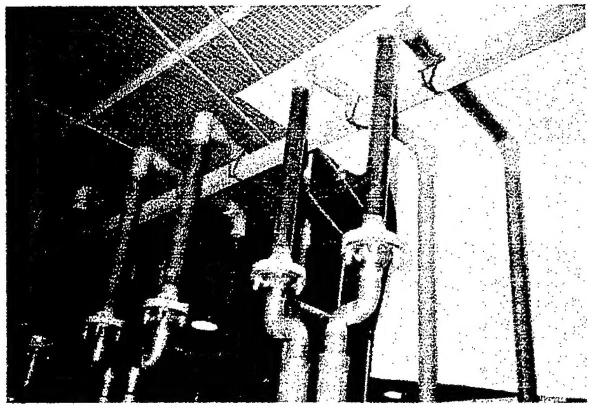

Figure 3. 1998 photograph of fiberglass pipe discoloration for 13V1001 (starboard side).

variations in color adhere to the rule that the warmer the pipe (i.e., higher temperature of the cooling water) the darker the color. However, similar to the Lualualei site, there are

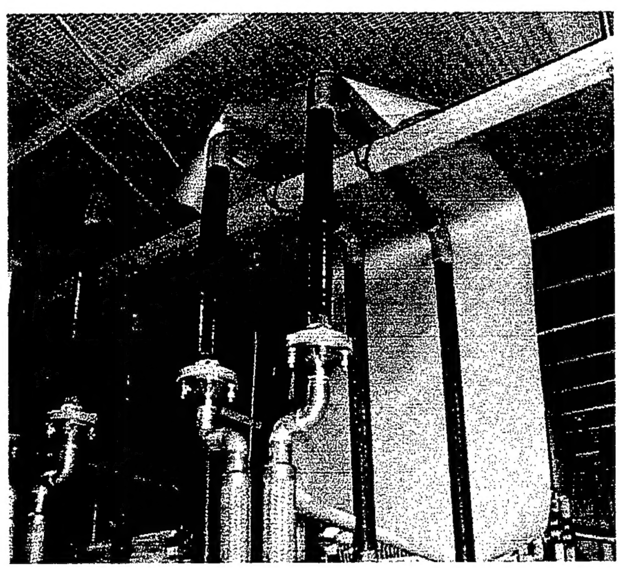

Figure 4. 2001 photograph of the fiberglass pipe discoloration for 13V1000 (starboard side).

light green/amber fiberglass pipe on the hotter exiting water with multiple variations to the general color distribution. There are cases where there is a light green/amber section

of pipe immediately attached to the exit flange, the next segment of pipe is dark amber and the remaining segment of pipe is light green/amber. The explanation is probably in the quality control of the fiberglass pipe batches, pipe age and ambient temperature of the situation. As can be seen in figures 3 and 4, the color of the fiberglass pipe has darkened slightly but retained the same color differentials. It may take a very long in service time (many years) before the Jim Creek site fiberglass pipe obtains a relatively even dark color like Lualualei.

Figure 5 shows how different the color changes can be obtained for the Green Thread pipe over a period of time. Several pieces of Green Thread pipe were stored in

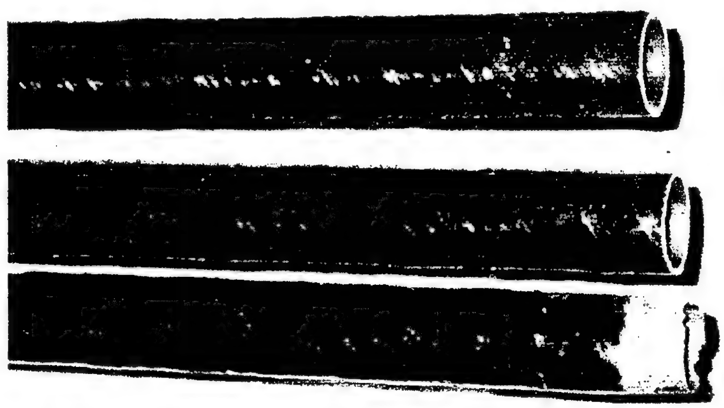

Figure 5. Green Thread pipe stored in warehouse at Lualualei site, March 2001.

the warehouse away from the transmission site at Lualualei. The temperature in the storage building at Lualualei was in the high 90s in March 2001. There apparently

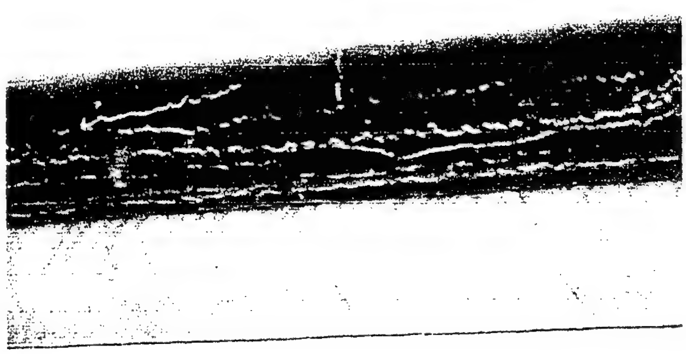

Figure 6. Green Thread pipe stored in warehouse at Jim Creek site, May 2001.

is no air conditioning in that building. We have an example of amber, light amber and close to the original medium yellow-green color. In contrast, several pieces of fiberglass

pipe that were left at the Jim Creek site after installation over 4 years ago still have the light yellow/green and darker green color (Figure 6). There is no air conditioning for the Jim Creek storage site but the temperature in the storage area probably rarely exceeds 80° F. There is no incident sunlight in the storage room. The pipe is virtually "in the dark" unless someone enters the room and turns on the light or opens the outside storage doors. This pipe from Jim Creek is also an excellent example of the quality control for color. There is already a piece of pipe which exhibits a much darker quality (green) which will turn more quickly into a dark/amber color when subjected to increased temperatures.

Conclusion

Based on the information obtained from the Smith Fiberglass Products Inc. technical representative and the data collected to date during the site visits, the darkening of the fiberglass pipe is a normal aging process and has no detrimental effect on the water cooling system or the indicated use of the fiberglass pipe. The color variations observed between the sites surveyed and within the sites indicates that there is a batch to batch variation in the production of the pipe (Figure 6). This color variation many disappear after several years of service life. The case in point is the Lualualei site which has a higher operational temperature and where almost 100% percent of the fiberglass pipe has changed from an amber to dark amber color. The Jim Creek site has a much larger variation of color for the Green Thread pipe. The other chemical and physical parameters that were measured have not changed significantly since the installation of the fiberglass pipe. These parameters can be easily monitored by station personnelwith some collected samples being returned to NRL for analysis. The change out frequency of the copper targets and the Barnstead cartridges has not changed since the installation of the Green thread pipe. There has been no noticeable change in the pH, dissolved copper or dissolved organic(s) in the water cooling system in the Green Thread pipe laboratory scale test setup.

REFERENCES

1. NRL Ltr Rpt 6110-131:RAL:May 1998

2. NRL Ltr Rpt 6110-132:RAL:June 2000

APPENDIX A

LUALUALEI, HI

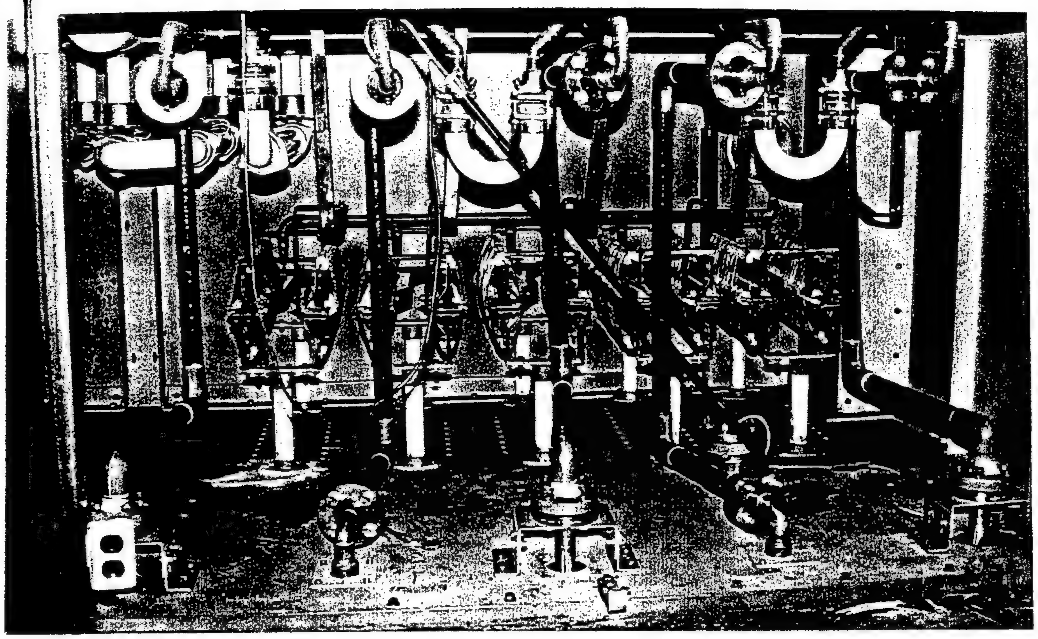

Figure 1. 1998 photograph of PA 1 (right side) fiberglass pipe showing color variations.

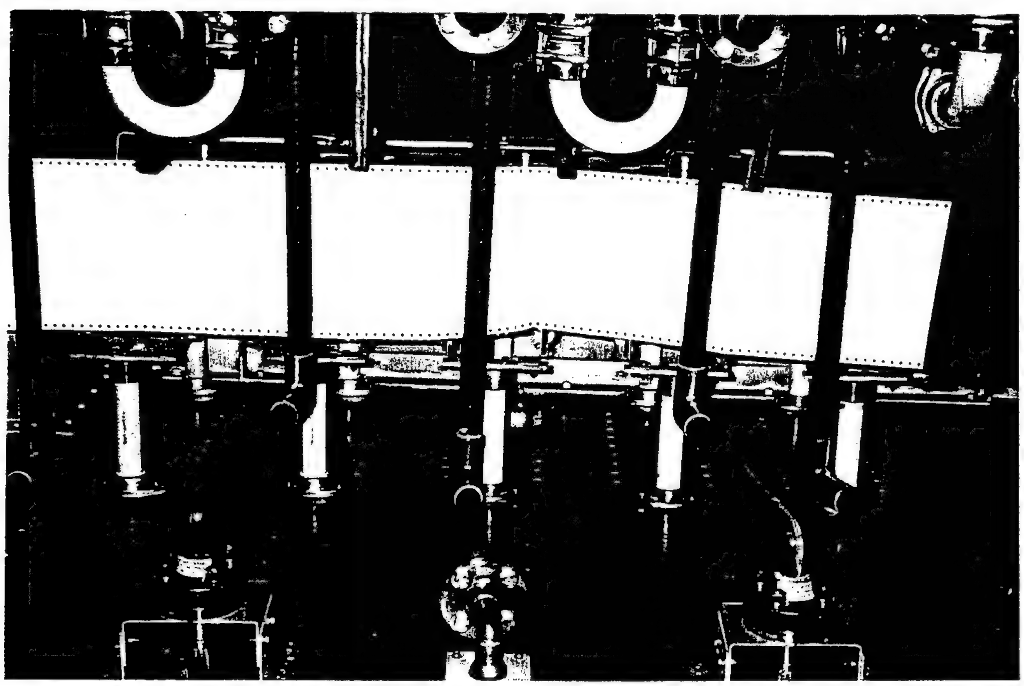

Figure 2. 1998 photograph of PA 2 (left side) fiberglass pipe showing color variations. Discontinuity of color in center pipe probably due to splice.

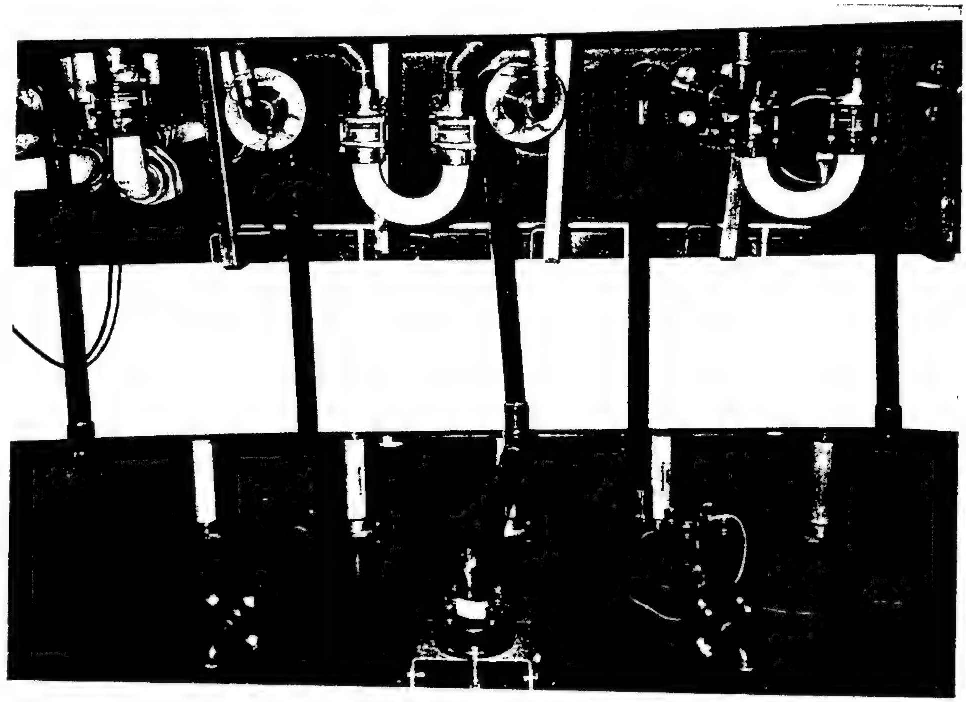

Figure 3. 2000 photograph of PA 1 (right side) fiberglass pipe showing that the color variations are almost nonexistent.

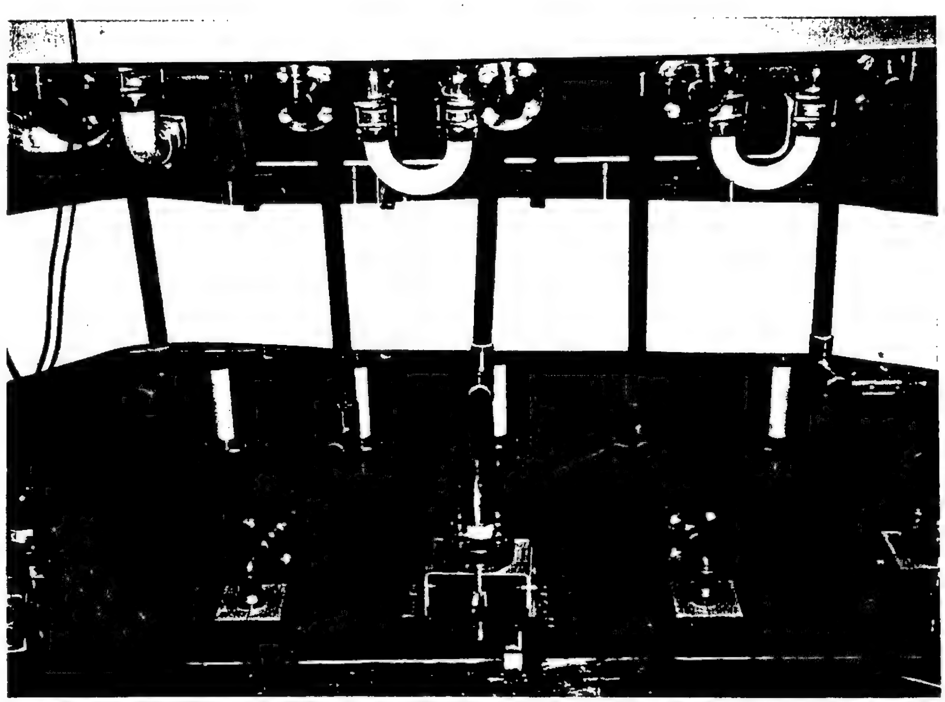

Figure 4. 2000 photograph of PA 2 (left side) fiberglass pipe showing color variations. Discontinuity of color in center pipe shown in figure 2 is not evident now.

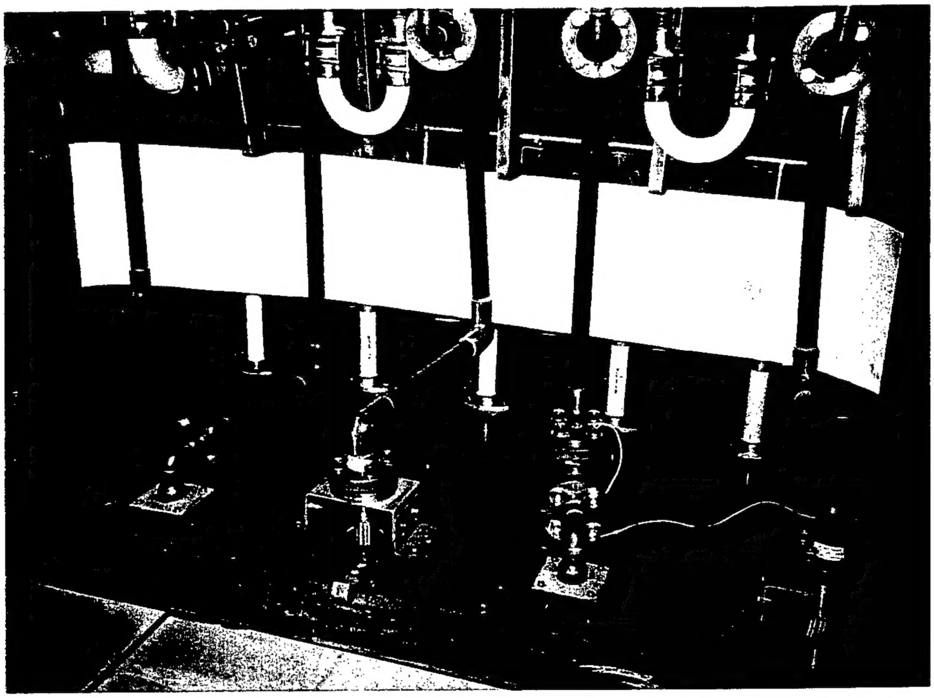

Figure 5. 2001 photograph of PA 1 (right side) fiberglass pipe showing that the color variations are almost nonexistent.

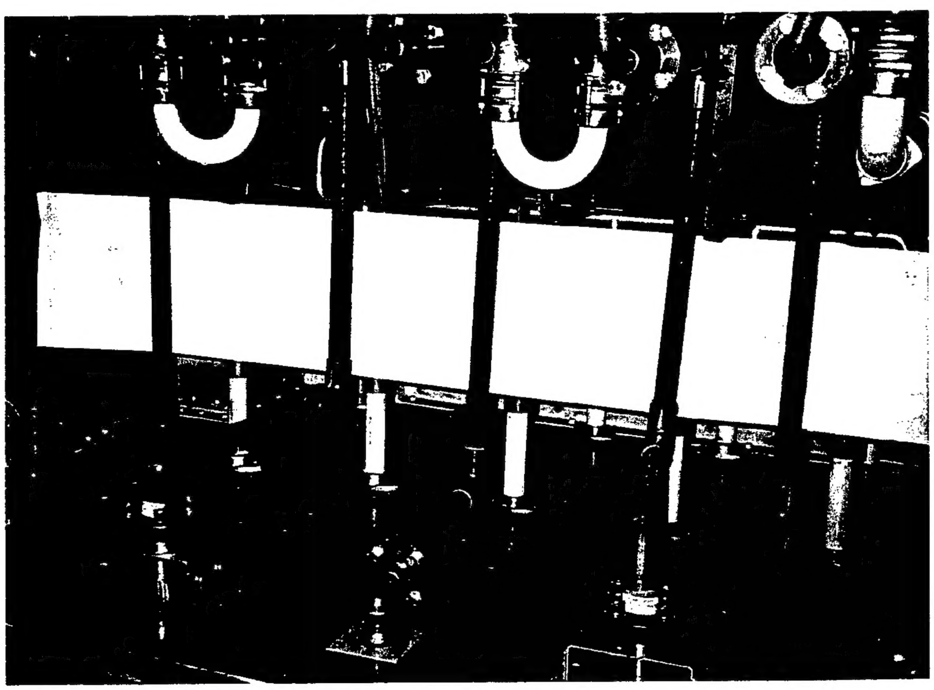

Figure 6. 2001 photograph of PA 2 (left side) fiberglass pipe showing no color variations.

JIM CREEK, WA

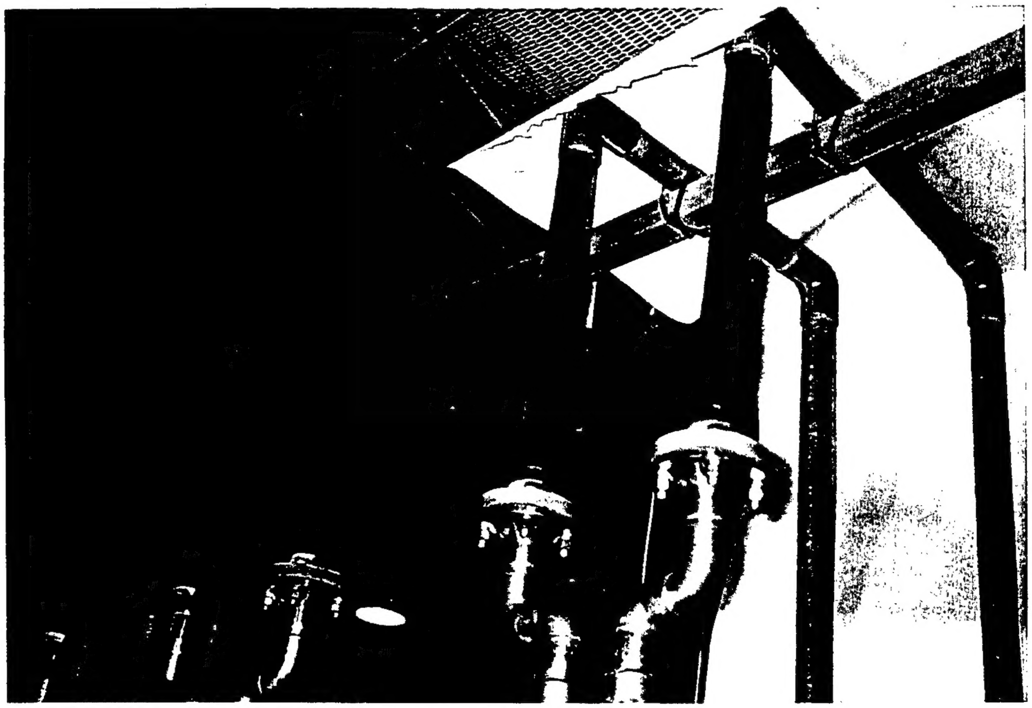

Figure 7. 1998 photograph of fiberglass pipe discoloration for 13V1001 (starboard side).

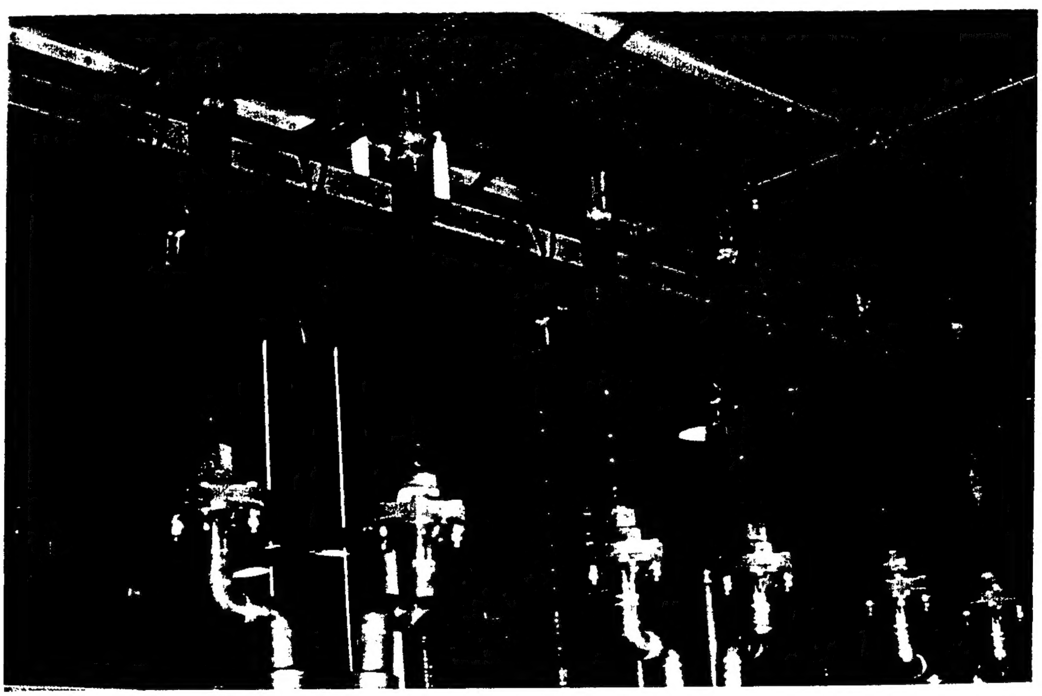

Figure 8. 1998 photograph of fiberglass pipe discoloration for port side PAs. Relatively even color distribution as compared to figure 7.

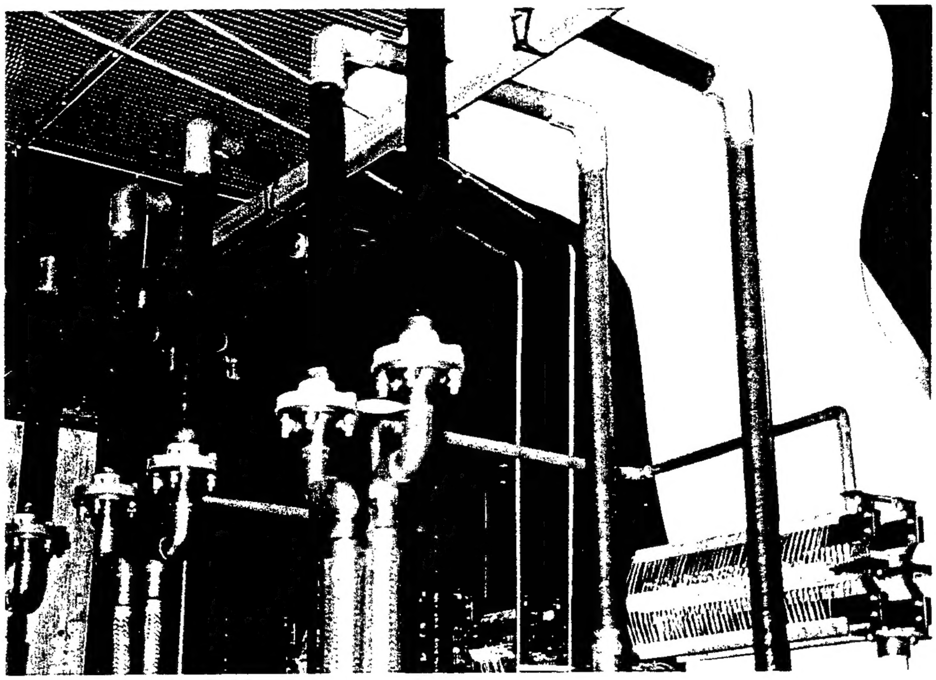

Figure 9. 2000 photograph of fiberglass pipe discoloration for 13V1001 (starboard side

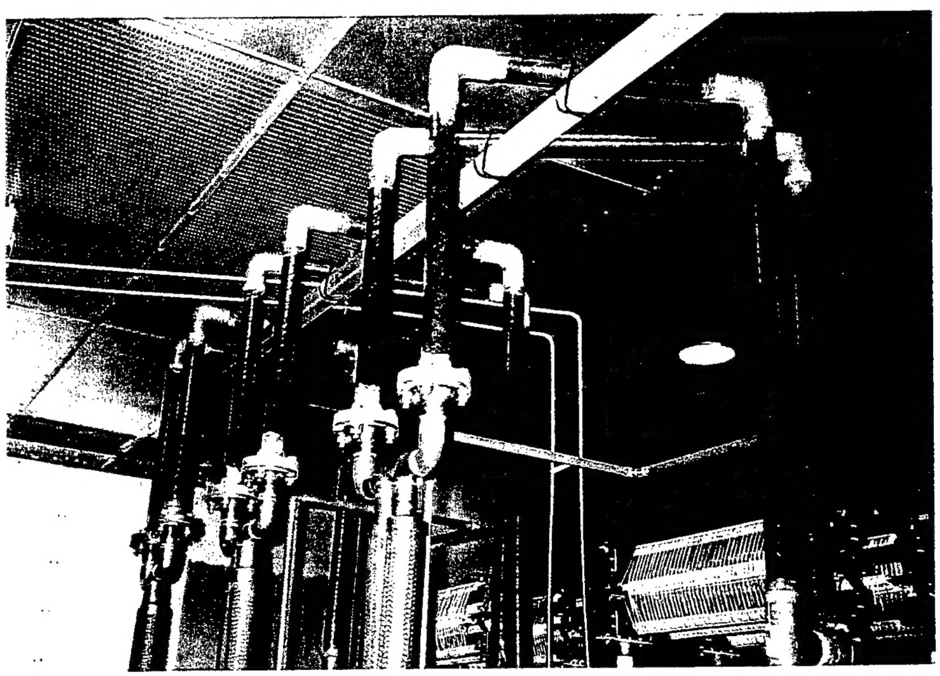

Figure 10. 2000 photograph of fiberglass pipe discoloration for port side PAs.

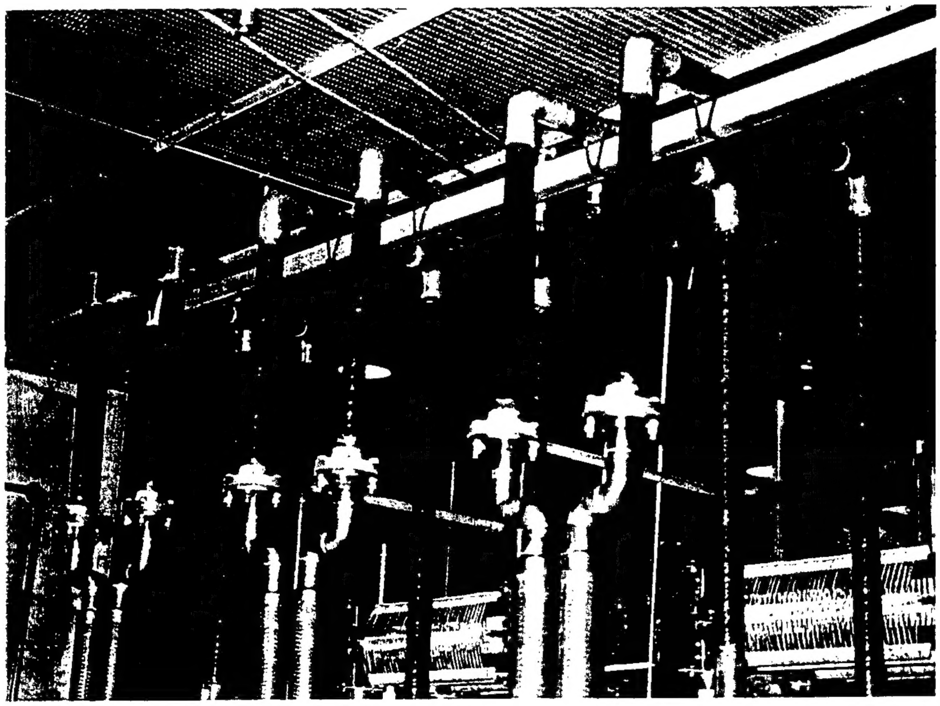

Figure 11. 2001 photograph of fiberglass pipe discoloration for 13V1001 (starboard side).

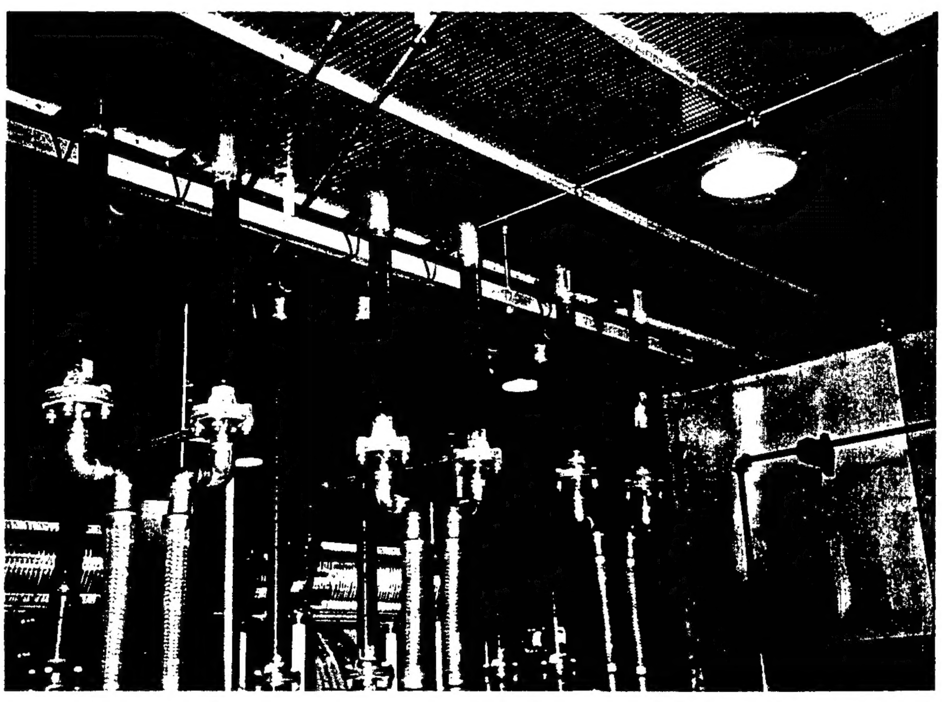

Figure 12. 2001 photograph of fiberglass pipe discoloration for portside PAs.